NSF Workshop on Composite Sheet Forming

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Workshop on Composite Sheet Forming

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THE EFFECT OF REINFORCING FIBER LENGTH ON SURFACE PROPERTIES OF THERMOPLASTIC COMPOSITES MADE BY SURFACE FINISHING/COMPRESSION MOLDING

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ABSTRACT

The Valyi SFC (surface finishing/compression) molding™ process[1, 2] was used to evaluate the effects of fiber length on the important performance properties required for class A thermoplastic composite panels. Class A moldings for automotive exterior use must meet demanding visual performance and demanding structural properties. The benefits of long fiber reinforcement in SFC molding have been reported[3]. The long fiber reinforced PP resins show enhanced stiffness and impact strength. Fiber length degradation in the SFC process is minimal. This paper reports on the surface properties of polypropylene composites made with short and long fibers. Surface read through of the fiber reinforcement is examined and methods for improvement are discussed. The SFC process combines resin extrusion, film finishing and compression molding in one low pressure molding process. In this process a finishing film is placed over a mold cavity, resin is extruded over the film from a traversing "coat-hanger" die and the mold is closed to form and finish the part in one step. This process has been successfully used to mold full-scale vertical and horizontal panel composites[4].

Introduction

The North American market for Automotive finishes is reported to be $2.3 billion[5]. Exterior panels represent a major portion of that market. By far, the dominate material used in exterior panels is painted steel, ~ 99%[6]. In the production process, steel sheet is stamped into parts followed by assembly and painting. These processes, though time honored, are highly polluting and high in energy consumption. The resulting parts add excess weight to the final product, further exacerbating the use of energy and indirectly adding to the pollution problem. Environmental pollution, recycalability and energy consumption are growing issues for the public. Forward thinking automotive executives are looking to new technologies to meet these challenges. The elimination of conventional painting[7] and the use of in-mold color on thermoplastic[8] are touted as future options. The stakes are high given that a state-of-the-art paint line for an assembly plant cost from $200 million to $500 million[8]. Likewise the collective pain to change to a new technology will be high for the OEM's and the supply chain. With growing pressure for attention to environmental and energy issues, the question is no longer one of if, but when and how to manage the change. Fortunately, the Plastics Industry can offer finishing, material and process answers for the problems of pollution, energy and recyclability.

The cost and performance of thermoplastic composites, in particular polyolefins (TPO's), place this polymer group in a unique position to solve major problems for the automotive industry. While pollution abatement, energy reduction and recyclability are the talking points; the vehicle cost out of the assembly plant is, most often, the ultimate driver in the decision process. TPO composites are the low cost material. Couple the low cost of TPO's with environmentally benign film finishes and a viable system answer emerges. "Film laminates are as durable as paint, and in some tests, such as chip resistance, show superior performance to paint[9]. The missing links are: a process to cost effectively make large structural plastic parts (an issue for all resin types), the ability to upgrade TPO performance to meet the physical requirements for both vertical and horizontal panels and the ability to maintain class A appearance after meeting the performance upgrade. Major progress has been made with the

Valyi SFC (Surface Finishing Compression) molding process to meet these challenges. Previous papers have reported on the basic process[1, 2], structural properties of reinforced SFC molded parts[4, 5] and class A appearance[10]. The manufacturing processes used to produce film finishes yield a very smooth, orange peel free surface[11]. Additives and fillers in the molding resin can degrade this appearance advantage. In this study, various reinforcing fillers were investigated and evaluated for their effect on the surface properties of distinctness of image (DOI), gloss and short and long wavelength reflection. Appearance degradation was most pronounced for long wave reflection on parts molded with long glass fiber (12.5 to 25-mm fiber length). A co-extrusion process was simulated to demonstrate a route to isolating the reinforcing layer from the class A surface. An alternate route to retaining class A with reinforcement is to place a non-woven glass-reinforcing mat on the back of a resin deposit where the resin has a small particle filler. An indirect method to mask surface waviness is to texture the surface, where permitted by design freedom. Texturing is not viable for painted parts due the need for pre-paint sanding and puddleling of paint in the texture. Parts are easily textured with a film finish in the SFC process.

Experimental

Equipment:

Figure 1 is a schematic of the molding equipment used in the Valyi SFC process. As shown the equipment has three units: (1) vertical clamping unit, (2) injection/plastication unit, and (3) melt strip deposition die. The production equipment, supplied by Engel, used to make parts for this study is shown in Figure 2.

Materials:

Red, white and black finishing films were provided by Rexam. The film construction was: 25-micron removable mask/50 micron clear coat/50 micron color coat/0.76 mm TPO substrate.

The resins used are listed in Table 2 by sample number. Sample S10-18 was made with glass fiber reinforcing mat manufactured by Astechnologies. All samples except S2-8 were made with a 1.3-oz non-woven veil molding aide placed between the film and the resin deposit. Xamax supplied the veil.

Sample Preparation:

The film finish was placed over a large mold cavity having a projected area of approximately 1.7 M^2. Molding resin was deposited over the film from the coat-hanger die. The die was retracted and the mold closed. Simulated co-extrusion parts were made by replacing shells from a first pass back into the mold and depositing a second resin layer containing long fiber additives. The mat reinforced sample (S10-18) was made by placing the reinforcing mat on top of hot resin deposited from the die followed by closing the mold. The hood shaped aluminum mold for the part was designed to have a variable wall thickness ranging from 4 mm (horizontal) to 6 mm (vertical sides). The original parts were made to demonstrate process feasibility and for characterization of physical properties. The test pieces for this study were cut from relatively flat areas (~ 4.5 mm thick) on each side of the horizontal part surface. The Measurements from the two sets were averaged. Clean room conditions, typical for class A production, were not in place. Part surfaces had slight curvature, which prevents precise measurement with instruments designed for flat surfaces. Accordingly, the data reported should only be evaluated for trends and guidance for future development.

Parts made to demonstrate process texturing were made in a "smooth" mold process. In this process a texturing material, foamed plastic netting or knit fabric, was placed in a smooth mold cavity. A film finish was placed over the mold cavity, resin deposited and the mold closed. The texturing material was easily removed from the demolded part surface. The texture of the texturing material was replicated in the part surface as shown in Figure 3.

Characterization:

Samples were selected from two screening trials in which a range of materials were investigated. Duplicate sample sets were measured for surface appearance properties associated with light reflection: short and long wave surface smoothness, distinctness of image and gloss. The measurements were made using

instruments located at the John Deere Technical Center in Moline, IL and the BMW assembly plant in Spartanburg, SC. Target values listed in the table are those used at the testing location. Each OEM will have its own specification for these attributes.

Results and Discussion

The structural merit for using long glass fiber in the molding resin can be demonstrated by observing Figure 4[3]. In this figure the apparent stiffness of the test plaque is plotted versus deflection at room temperature. As shown, the stiffest parts were obtained with a woven glass/PP mat. The 30% short carbon fiber reinforced PP initially displays an equivalent stiffness but this decreases at the larger strains. The 40% long glass is not as stiff as the woven glass but has significantly stiffer properties than the 30% short glass. Figure 5 shows the benign effect of the SFC molding process on the long fibers. Fiber length is virtually unchanged after extrusion and molding. Resin modification and advanced reinforcing materials will be necessary for TPO's to expand from vertical to horizontal panels. The advantages of the advanced reinforcing materials are offset by degradation of the finished surface. Surface appearance is made up of color and gloss elements. Sub elements of gloss relate to focus on the surface, waviness, and focus on the reflected image, DOI (see Figure 6[12]). Resin fillers tend to have their greatest effect on waviness. This is shown in side by side photos of parts molded with talc, short glass fiber and long glass fiber fillers, Figure 6. In this study, the greatest visual degradation is observed for the long wavelength and the orange peel measurements. These two measurements represent two different ways of reporting what the eye sees with regard to surface waviness. The results are shown in Table II (and in selected photos, Figure 7). An unfilled resin and resins filled with talc and short glass fiber (samples S2-8, S3-14 and S3-5) fall in the range of acceptability for horizontal panels on the long wave length scale.. These same panels exceed the target range for orange peel; i.e. due to very low orange peel, at least on this OEM's scale. Some orange peel may be allowable and, in fact, is inherent in state-of-the-art paint technology. DOI and gloss are reasonably consistent over the sample range. The variance between the 20° gloss measured with the ACT instrument and the Gardner instrument is believed to be due to the effect of panel curvature on the Gardner readings. The samples molded with long fiber filled resin (samples S7-3, S8-3, S8-20 and S8-6) were all outside of the target range for both long wave length (>> 8) and orange peel measures (<5).

Two approaches were used to investigate routes to improved surface appearance for long wave length and excess orange peel measurement (<5). Low orange peel (>7) was not addressed and is considered an advantage for film finishes. The direction taken was to isolate the film finish layer from the long glass resin layer by molding a small particle filled resin (talc or short glass) between the film and long glass material. One approach is to accomplish this in a co-extrusion or sequential extrusion stepped process. A simulation was used to test this approach in the absence of co-extrusion or in-line sequential extrusion equipment. The parts made in this manner are D9-3 and D9-11. The D9-3 part made with a talc first resin layer meets the long wave target. The part made with short glass as the first resin deposit (D9-11) measures over the target but is significantly closer to target than the parts made with long fiber resin. A second approach tested was to use a reinforcing mat as the structural member. A first deposit of short glass fiber resin was made and the reinforcing mat place directly on top of the hot resin. The composite was then molded to make the part (S10-18). This part measures in the target range for long wave length and exhibits low orange peel.

Avoiding the surface waviness issue by texturing is not an option in most applications. A viable means to texture parts does; however, give an option to add style and enhancement to a design concept and permit cost efficient part reinforcement. Samples textured in a "smooth" mold using texturing inserts are shown in Figure 8.

Conclusions

Thermoplastics are used extensively today for vertical panels such as fascia and rocker panels. Structural limitations prevent their use in large horizontal panels. The Valyi SFC molding process demonstrates a new method to mold and reinforce thermoplastic composites. The most straightforward solution for reinforcement is to use long fibers (glass or carbon) in the molding resin. While improving strength and stiffness, the part surface is

degraded. This study indicates that co-extrusion, sequential extrusion or placement of a reinforcing mat with a first deposit of small particle resin will bring the TPO system in line with horizontal part requirements. Additional sub surface structure (as used today with metal frame members) may be necessary for the final solution. Further study is needed to determine the optimum particle size range and loading level for the first molding resin deposit. The study should include talc, glass, mica and nanocomposite clay filled thermoplastics. If cost is supreme, then texturing is an option to minimize observable defects in light reflection and at the same time achieve style enhancement.

Acknowledgements

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(12) BykGardner, "How to Quantify Orange Peel", www.bykgardnerusa.com.

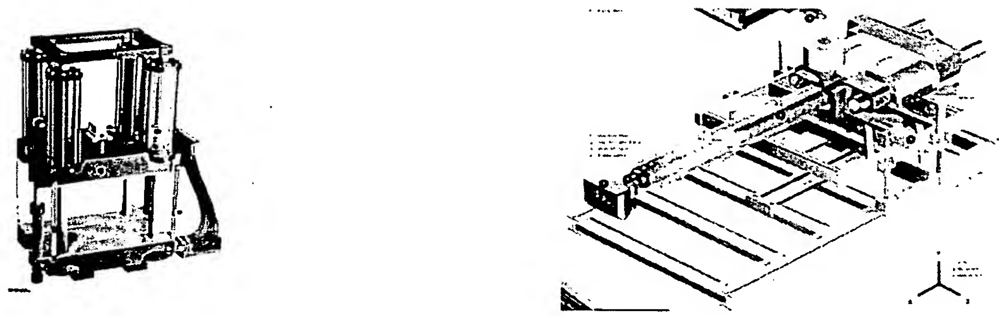

Figure 1. Schematic SFC molding equipment.

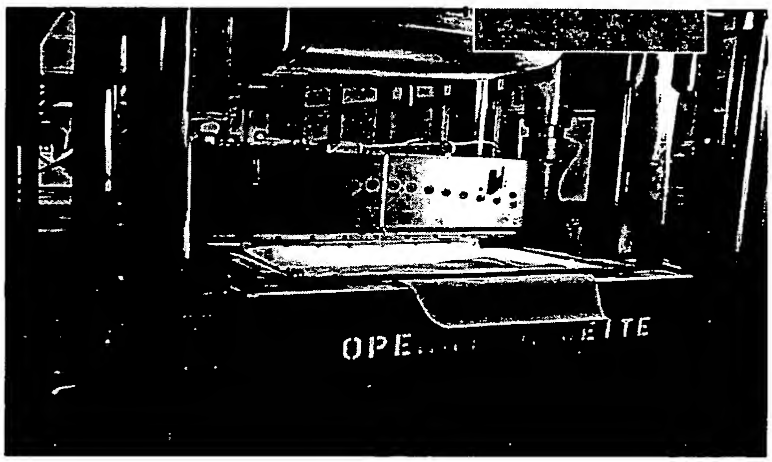

Figure 2. Full-scale production die and mold used in SFC process.

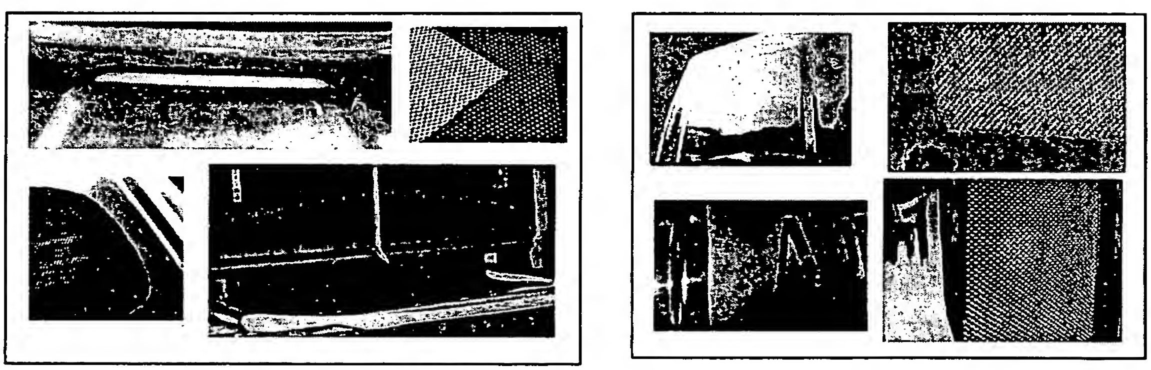

Figure 3. Smooth mold texturing procedure (left) and smooth and textured parts (right)

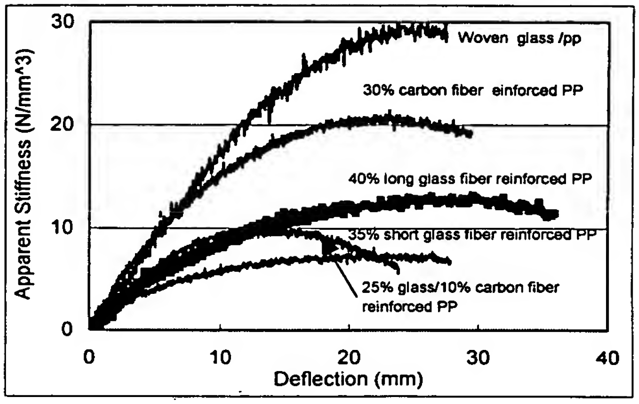

Figure 4. Apparent stiffness for different fiber reinforcement polypropylene resins at room temperature

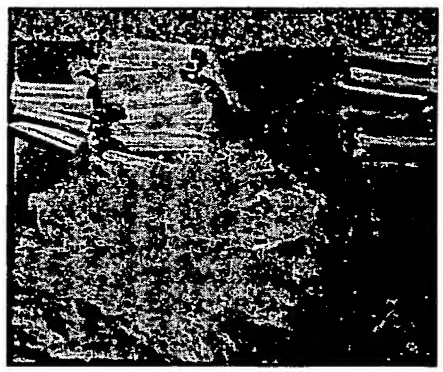

Figure 5. Fiber length and distribution after molding.

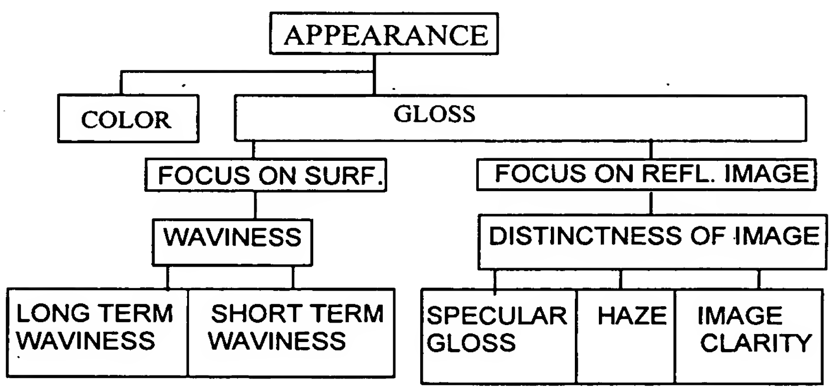

Figure 6.Diagram of surface appearance phenomena.

S2-8 S10-18 S8-3

Figure 7. Photos of parts made with unfilled (S2-8), 35% short glass filled/glass mat (S10-18) and 40 % long glass – 1"(S8-3).

Table I : <u>List of resins</u>

Sample No.	Part Description	Resin Description/Reinforcement
S2-8	Red Film Neat Resin	Marlex PP Copolymer
S3-14	White Film Talc filler	Basell CB259 talc filled
S10-18	Red Film Short glass filler Reinforcing Mat	Basell 7155 short glass/Astecnologies PP-glass mat (PP glass mat: chopped long glass, ~ 8 mm) in recycled PP resin)
S10-5	White Film Short glass filler	Basell 7155 short glass
D9-3	Black Film Co-ex. simulation Talc/Lg glass fillers	Basell CB259 first layer/ Ticona Celstran PPGF 1.25 cm 40% glass second layer
D9-11	Black Film Co-ex. simulation Sht glass/Lg glass filler	Basell 7155 short glass first layer / Drift X11506 2.54 cm 40% glass second layer
S7-3	Red Film Long glass filler	Ticona Celstran PPGF 1.25 cm 40% glass
S8-3	Red Film Long glass filler	LNP Verton MFX 7008 2.54 cm glass
S8-20	White Film Long glass/ Long carbon blend	Montsinger PP30G10C 1.25 cm 30 % glass/10% carbon
S8-6	White Film Long Glass	Drift X11506 2.54 cm 40% glass

Table II: **Measurement of part surface properties**

Sample No.	Description	Long[1] Wave	Short[1] Wave	ACT[2] Orange Peel	ACT[2] DOI	ACT[2] 20° Gloss	Gardner[3] 20°/60° Gloss
	Target: Vertical Horizontal	=/<26 =/<8	=/<35	5-7[4]	70+		
S2-8	Red Film Neat Marlex Resin	5.3	33	7.8	91	70	54/78
S3-14	White Film Talc filler	5.4	30	8.1	92	73	57/78
S10-18	Red Film Short glass filler Reinforcing Mat	6.3	27	7.8	94	72	56/79
S10-5	White Film Short glass filler	6.6	27	7.4	91	74	64/78
D9-3	Black Film Co-ex. simulation Talc/Long glass fillers	7.1	33	7.4	91	66	54/76
D9-11	Black Film Co-ex. simulation Short glass/Long glass filler[5]	10	36	6.2	88	57	57/75
S7-3	Red Film Long glass filler	19	29	4.8	87	76	58/79
S8-3	Red Film Long glass filler	19	31	4.0	85	76	54/79
S8-20	White Film Long glass/ Long carbon blend	23	29	4.7	75	85	51/78
S8-6	White Film Long Glass	26	28	3.9	85	78	56/78

Notes:

1. Courtesy of BMW-Spartanburg, SC – Instrument: Gardner Wave Scan Plus meter.

2,3. Courtesy of John Deere – Moline, IN – Instruments: ACT AppearMax and Garner Gloss meter

4. The orange peel scale is 1 to 10 with one representing very high orange peel and 10 no orange peel.